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6. AUTHOR(S)
Christopher von Alt

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Woods Hole Oceanographic Institution
98 Water Street
Woods Hole, MA 02543-1053

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The following summarizes the goals that were met and provides an overview of the system configuration. Also enclosed in a chart summarizing the extensions and modifications to the project and a letter from Captain Callahan to WHOI documenting the success of the technology transfer to Navy fleet operations.

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Woods Hole Oceanographic Institution

Oceanographic Systems Lab

Woods Hole, MA 02543

Tel: 508-289-2290

FAX 508-457- 2104

internet: chris@osl.whoi.edu

September 4, 1996

Dr. Steven E. Ramberg
Office of Naval Research
CODE 321
800 North Quincy Street
Ballston Tower One
Arlington, VA 22217-5660

Ref: Contract #N00014-90-J-4050 "Teleprobe Integration"

Dear Dr. Ramberg:

The Oceanographic Systems Lab (OSL) has completed the above referenced contract, including the attached list of extensions and supplementary contracts. The Teleprobe Survey System (subsequently referred to as FOSS-1) was delivered to NAVO and tested aboard the USNS Wilkes out of Hawaii in March 1993. The FOSS-1 system has been supported and enhanced by the OSL during the last three years of NAVO missions. Subsequent contracts that have contributed to this support are N00014-93-C-0097, "Fiber Optic Search System Development" and N00014-94-C-0102, "Deep Ocean Unmanned Vehicle Program."

The enclosed report summarizes the goals that were met and provides an overview of the system configuration. Also enclosed is a chart summarizing the extensions and modifications to the project and a letter from Captain Callahan to WHOI documenting the success of the technology transfer to Navy fleet operations.

Sincerely,

Christopher J. von Alt
Head, Oceanographic Systems Lab

CC: C. Ingram, R. Tanner, A. Henry, NRL, DTIC, S. Ferreira

Enclosures: Report, letter, table, publications (3)

Final Report
Contract #N00014-90-J-4050
"Teleprobe Integration"

The Oceanographic Systems Lab (OSL) has completed the above referenced contract, including the attached list of extensions and supplementary contracts. The Teleprobe Survey System (subsequently referred to as FOSS-1) was delivered to NAVO and tested aboard the USNS Wilkes out of Hawaii in March 1993 at which time the tether termination failed and the system was lost. The system was recovered after 70 days on the bottom and was prepared for sea in less than two days. The acceptance cruise was very successfully completed in May 1993.

The FOSS-1 system has been supported and enhanced by the OSL during the last three years of NAVO missions. Subsequent contracts that have contributed to this support are N00014-93-C-0097, "Fiber Optic Search System Development" and N00014-94-C-0102, "Deep Ocean Unmanned Vehicle Program."

The following summarizes the goals that were met and provides an overview of the system configuration. Also enclosed is a chart summarizing the extensions and modifications to the project and a letter from Captain Callahan to WHOI documenting the success of the technology transfer to Navy fleet operations.

Program Goals

- Overcome deficiencies in deeply towed robotic systems.
- Establish clear, open and effective lines of communication between operators (NAVOCEANO) and technical support group (WHOI/OSL)
- Involve operators in system design, assembly, and evolution.
- Field experiences are "fed back" to technical support group to improve reliability, minimize spares requirements, improve maintainability and address problem areas
- Technology is "fed forward" through documentation, field training and at sea support.
- Minimize data recording costs.

FOSS System Overview

The integration of the teleprobe survey system into the newly named FOSS-1 (Fiber Optic Survey System) incorporated the vehicle and support systems; the upgraded man-machine interface of the control system software and data telemetry; the implementation of the navigation system upgrade with RATS (Relative Acoustic Tracking

System); upgrade of video imaging by adding the scientific grade CCD camera and data storage system; and design and implementation of an integrated cable handling system and heave compensating crane.

The MCM (Mission Control Module) van supports all system operations from three crew stations. All vehicle operations, data collection, logging and monitoring functions as well as cable handling system and communications with the ship's bridge are centralized for a crew of three operators.

The MCM staff consists of a quality assurance engineer who verifies that all equipment is operating properly, controls data acquisition, media labeling, data logging and routing from the Engineering station. The Navigator controls the position of the sled in the X-Y axis, operates the side scan sonar and communicates with the bridge. The Flyer controls the vehicle position in the Z-axis, operates the vehicle thrusters, winch and heave compensating crane.

The VMV (Vehicle Maintenance Van) provides an environmentally controlled garage on deck for at sea maintenance work with oil storage and transfer equipment for the vehicle pressure compensation system and power supplies and interface to the MCM that allow on deck operation without the high voltage cable. Shock mounts and tie-downs protect the vehicle during shipment. A second van provides spares storage and static controlled electronic maintenance work benches.

The NAVCOM (Navigation and Communications) van provides a secure environment for mission planning, media storage and review facilities for ESC images, Q-MIPS and navigation data. A Sperry Mark 50 gyro compass and Magnavox Inmarsat link provide high speed data transfer.

The Cable Handling System and heave compensating crane are consolidated into two standard 8'x20' ISO shipping containers and one double length (due to boom length) ISO container for the crane. The system consists of a storage winch and level wind with a capacity for 36,000 feet of cable. The traction winch and a redundant electro-hydraulic power unit integrated in one frame provide 328 ft./sec at 18,000 lbs. load. The winch system connects to the MCM via an electro-optic slip ring assembly, provides monitoring instrumentation including pressure and temperature sensors and remote operation from the MCM. Crane features include both latching and slewing mechanisms.

The FOSS-1 Vehicle

The vehicle accommodates a wide area video imaging system, 35mm and digital cameras, an extensive array of acoustic sensors and processors, and a suite of platform sensors. Two thrusters providing a nominal thrust of 80 lbs. each allow the vehicle to pivot on its axis for precise positioning of the imaging systems. Joystick control from the Flyer's station allows manual control or auto-pilot for constant heading with lateral offset situations. A clear cover allows visual inspection of indicator lights to aide in maintenance and trouble shooting of the oil-filled pressure compensated electronic junction box.

Fiber Optic Data Telemetry System

The data telemetry system utilizes a two fiber cable to accommodate both high and low bandwidth data. Features include 10 high speed data channels; fully synchronized operation; automated laser monitoring; 12 bit 200k-samples of analog data; a 1MB/sec RS-488 interface; custom interface cards for Klein side scan sonar, digital ESC cameras and ethernet.

Platform Sensors

Platform Sensors include the following suite of oceanographic sensors:

- a CTD (Conductivity, Temperature, Depth),
- OBS (Optical Backscatter Sensor),
- AMU, consisting of a 3-axis gyro and accelerometer integrated with the RATS navigation system (Relative Acoustic Tracking System),
- Flux gate compass,
- Ground fault detection system,
- Ground fault interrupt system,
- Subsystem current and voltage monitoring/protection,
- Termination load cell providing cable tension monitoring at the vehicle.

Acoustic Sensors

A broad range of acoustic sensors deliver comprehensive data and services to the analysis team in both the MCM and NAVCOM vans.

- Klein 595 Side Scan Sonar

  Two differential transceiver boards, one tuned to 100 kHz, the other 500 kHz for port and starboard side scan are acquired and displayed in the MCM van as well as in the NAVCOM van where data analysis takes place utilizing the Triton Q-MIPS sonar imaging system.

- EDO CTFM Obstacle Avoidance Sonar
- 2 wide band hydrophones
- Navigation system support

  Integrated Long Base Line Tracking

  Emergency Recovery Pinger

Imaging System

- **The snap shot imaging system** has 2 Benthos 372 35mm still cameras with improved data chambers and 600 watt-second strobes. Configuration control and interactive timing of strobes and cameras is provided through the telemetry system. Additionally a pair of Electronic Still Cameras (ESC) output to a CDROM data storage system.
- **The video imaging system** provides two black and white and two color video cameras to a variety of monitors, image enhancement tools and data storage media. All housings are interchangeable for any of the cameras and control, routing and zoom (for the Sony 3-chip color) are managed from the engineer's console. Video illumination is provided by 4 titanium 175 watt thallium iodide

Summary

Three years of operation have shown that FOSS-1 has successfully integrated commercial off-the shelf (COTS) oceanographic sensors with a state-of-the art fiber optic telemetry system and software control system to provide a comprehensive suite of instrumentation. The system is completely containerized for efficient staging, shipping and maintenance in the field. It has been used on a variety of vessels and can be operated and maintained by a relatively small crew for extended periods at sea.

Direct scientific advances achieved by this program include the design and development of a new fiber optic cable; development of new tether termination techniques; design and development of an advanced fiber optic telemetry system allowing wide bandwidth transmission of data; development of a low cost wide area video imaging system utilizing COTS components; and the development of an advanced man-machine interface for computer control of system.

FOSS has become an important scientific tool for increasing our understanding of the ocean. It has bridged basic and applied research and resulted in the rapid transition of technologies for use in the fleet for making the scientific measurements needed to support fleet objectives.

13405000 FOSS Teleprobe

2-13-90	Teleprobe Enhancements Proposal 6366.0	
8-29-90	Original Contract N00014-90-J-4050	$419,000
4-26-91	Teleprobe Additions: Supplement to ONR Grant N00014-90-J-4050. Proposal 7121.0	
7-25-91	Mod 1, Increment Funding	$221,872
6-14-91	Teleprobe/DAMBS Integration: Supplement to ONR Grant N00014-90-J-4050. Proposal 7219.0	
9-18-91	Mod 2, Increment Funding	$335,000
9-3-92	Teleprobe Integration: Supplement to ONR Grant N00014-90-J-4050. Proposal 7944.1	
1-11-93	Mod 3, Increment Funding	$1,125,098
4-26-94	NFE to 30 June 94	

DEPARTMENT OF THE NAVY
NAVAL OCEANOGRAPHIC OFFICE
STENNIS SPACE CENTER, MS 39522-5001

Chris, Roger, Ned
Congratulations.
Well done gentlemen

IN REPLY REFER TO:
5060
Ser N344/90057462

cc Jim, Dick, George

26 JUL 1994

Dr. Robert B. Gagosian, Director
Woods Hole Oceanographic Institution
Woods Hole, MA 02543

Dear Dr. Gagosian:

I would like to take this opportunity to commend the performance of Mr. Christopher von Alt, Senior Engineer, Oceanographic Systems Laboratory, and his project team, including Mr. Roger Stokey and Mr. Ned Forrester, for their superlative efforts during the design, integration and delivery of the Fiber Optic Survey System (FOSS) to NAVOCEANO. With its state-of-the-art sensor suite and fiber optic communications technology, FOSS provides the U.S. Navy with a much needed tool for adding to the body of scientific knowledge of the world's deep oceans.

During the development of FOSS, Mr. von Alt and his team professionally addressed a complex series of technical and programmatic risks in attempting to integrate a formidable array of sensors into a reliable operational system. Mr. von Alt's team delivered FOSS on time and within budget. The system was successfully employed during a major survey operation in 1993, and just completed pre-deployment refurbishment and at-sea testing in preparation for another operation this year. Since delivery, and throughout subsequent operations, FOSS consistently performed numerous demanding tasks in a manner exceeding all expectations.

Mr. von Alt and his team are commended for their outstanding performance during the arduous FOSS development process. The joint accomplishments of the NAVOCEANO and Woods Hole Oceanographic Institution (WHOI) FOSS development teams would not have been possible without Mr. von Alt's invaluable contributions. His efforts reflect great credit on WHOI.

Sincerely,

T. E. Callaham

T. E. CALLAHAM
Captain, U.S. Navy
Commanding Officer

Society of Naval Architects and Marine Engineers
New England Section
Fiftieth Anniversary Proceedings
May 6-8, 1994, Wood Hole, MA

Bobbing Crane Heave Compensation for the Deep Towed Fiber Optic Survey System

Michael J. Purcell and Ned C. Forrester - Woods Hole Oceanographic Institution

ABSTRACT

The Fiber Optic Survey System (FOSS) is an underwater vehicle designed for high resolution observation of the seafloor. Towed with the standard 17.3 mm (0.68 inch) fiber optic, electromechanical cable at speeds up to 1 m/s (2 knots), it may be deployed at depths from 100 meters to 6000 meters in wave conditions up to sea state 4. These parameters result in large variations in deployed cable length, towing angle, static cable tension and cable/vehicle dynamic response to wave induced ship motions that are transmitted into the cable. Computer modeling of the cable/vehicle system indicates that certain combinations of towing parameters result in excessive vehicle motion or high dynamic cable tension. This paper addresses the effectiveness of heave compensators, particularly a bobbing crane, in reducing induced motion and cable tension. Both a passive and a combination active/passive system have been considered. Modeling results indicate that the passive system reduces high dynamic cable tensions, but eliminating induced vehicle motion requires an active component.

1 INTRODUCTION

Towed underwater vehicles and instruments are used extensively for exploring the ocean. Examples include biological sampling, sonar mapping of the seafloor and underwater photography. A concern in any towed system is its response to ship motion that is transmitted into the tow cable. Since lateral motion is quickly dampened by drag, the primary concern is axial motion of the cable. Axial cable motion may induce motion of the vehicle that disrupts its ability to perform a task or collect quality data. Worse, generated dynamic tensions may combine with the static tension to exceed the cable breaking strength or result in fatigue failure at the cable termination. As seas increase, the risk of cable failure increases and the tow system may have to be retrieved, resulting in costly delays in completing a survey or scientific study. Integrating a heave compensator with the towed system can reduce the ship induced vehicle motion and dynamic cable tensions. This may allow the system to be deployed during wave conditions that would otherwise require retrieval.

Heave compensators have been used in the ocean drilling industry and in towed systems for some time. Types of heave compensation systems include: constant tension winches, ram tensioners and bobbing cranes. Many of these systems are passive in that they respond to the ship motion and changes in cable tension rather than being driven based on measurements of these values. With a towed vehicle system, an attempt is made to keep the ship tow point stationary or to deploy and retrieve cable to compensate for the ship motion. With the exception of the constant tension winch (Mitchell, 1992), these compensators include pneumatic and/or hydraulic systems that store energy as tension increases. This energy is used to return the compensator to its original position as tension decreases. Initially, the fluid system pressure must be set to support the static load, which is based on the towing parameters. As towing conditions such as deployed cable length change, the system pressure must be modified to balance the new static load. Another important consideration is the range of the heave compensator. Sufficient compensator range is required to ensure that the compensator will not reach a travel limit, which would result in high dynamic tensions. Ship motion is dependent on wave conditions and the ship response to the waves. The required compensator range may be established based on knowledge of ship response and planned maximum sea state.

The type of heave compensator selected often depends on the application's requirements. In some

This work was supported by the US Naval Oceanographic Office and the US Office of Naval Research under Contract No. N00014-93-C-0097.

Software Design Techniques for the Man Machine Interface to a Complex Underwater Vehicle

Roger P. Stokey
Oceanographic Systems Laboratory
Department of Applied Ocean Physics and Engineering
Woods Hole Oceanographic Institution
Woods Hole, MA 02543

Abstract — As underwater vehicle complexity grows, so does the manpower needed to operate and maintain them. This paper describes the architecture of the software used to operate FOSS [Fiber-Optic Survey System], a complex full ocean depth towed vehicle. This system operates using the UNIX operating system and the X Windows graphical user interface. It is in constant serial communication with 25 different devices both on the vehicle itself and in the shipboard control van, providing centralized control as well as automatic fault detection, enhancing vehicle reliability while reducing operator work load, and thus significantly lowering operational costs.

The paper explains the distributed architecture used to continually monitor over 70 analog channels, including leak detectors, current sensors, voltage sensors, and ground fault detectors and the techniques used to provide immediate warnings to the operator when any signal falls outside of allowed parameters.

Also detailed is how the system manages and catalogs the media used by the vehicles 2 electronic still cameras, 4 subsea video cameras, and the side scan sonar; providing centralized indication of the recording time remaining for each system; logs of the media recorded; and even printed labels.

The paper describes the techniques used to receive data from the various sensors, and redistribute it in proper format to all other systems, thus continually tagging all data streams with time, date, vehicle and ship position, vehicle attitude, water temperature, and transmissometer data.

I. INTRODUCTION

The introduction of the 17mm electro-optic cable has made possible deep towed tethered vehicles that can generate a veritable flood of data. In recent years vehicles have been built with fiber optic telemetry systems that are allowing a greater number of instruments to be simultaneously deployed at full ocean depth. However this increased data bandwidth also means greater complexity to be managed.

FOSS (Fiber Optic Survey System) is a full ocean depth (6000 meter) sled towed using a 17mm fiber optic cable. In its usual configuration FOSS carries four video cameras, 2 electronic still cameras, two 35mm cameras, a dual frequency sidescan sonar, altimeter, attitude measurement unit, sub-bottom profiler, pressure and temperature sensors, transmissometer, compass, forward looking CTFM sonar, two thrusters, as well as lights and strobes for the cameras. These systems are mounted on a 4.3 meter long stainless steel frame.

The ship based mission control module is built into a 6.1 by 3.3 meter van, and designed for three operators: a flyer, whose job it is to keep FOSS within 5 or 10 meters of the bottom; the navigator, who navigates the vehicle and controls the survey; and a quality assurance engineer, whose job is to verify that all FOSS sub-systems are operating properly, that all instruments are functioning correctly, and that all the data is being properly recorded. It is the tasks of this last individual that the FOSS software is designed to facilitate.

FOSS has been designed to be easy to maintain. Part of this ease of maintenance is accomplished via the control program which provides text based fault messages when it detects that something is wrong with the vehicle or with any of the surface equipment. In addition, the program provides a common interface to most of the instruments, thus simplifying operator training.

At this time FOSS has completed successful operations off the Hawaiian Islands, Japan, and Nassau in the Bahamas. Because both the vehicle and its control van are designed for standard cargo containers, shipping the system world wide has presented few problems.

II. VEHICLE ARCHITECTURE/DESIGN TRADEOFFS

The FOSS control program is designed around the UNIX operating system, using the Openlook graphical user interface and the XWindow system. It runs on a ruggedized SPARC II workstation located in the mission control van. This SPARC is connected via ethernet and twenty-five R3-232 serial lines to virtually every instrument on the vehicle and every system in the mission control van, including VCRs, the electronic still camera deck units, the uninterruptible power supply, the side scan sonar hardcopy unit, QMIPS_{tm} (used for recording side scan data), a 30x20 video router, the time-code generator, and the high voltage supply for the vehicle tether.

UNIX was selected because at this time, it is a far more robust operating system than any of the PC based operating

This work was supported in part by the US Naval Oceanographic Office and by the US Office of Naval Research under Grant No. N00014-90-J-4050, and by the National Science Foundation under grant No. OCE89-12891.

RATS:
Relative Acoustic Tracking System for the TOSS Vehicle System

(Revised 4/1/96)

1.0 Introduction

The Oceanographic Systems Laboratory at Woods Hole Oceanographic Institution (WHOI) was originally funded by ONR to develop a highly accurate relative tracking system based on spread spectrum signaling techniques for tracking of the TROV vehicle with respect to its host platform. This use of wide band signal design has dramatically improved the accuracy possible with Ultra-Short Baseline Arrays in the presence of noise and multipaths, and also lends itself to LPI (Low Probability of Intercept) applications. The original "ATS" was based on commercial VME bus hardware, which was ideal for the initial development, but large, power hungry, and expensive from a production standpoint. The "ATS" system was miniaturized for the SSAR (Surface Suspended Acoustic Receiver) program under DARPA funding and was successfully tested at AUTEC in August, 1994. The miniaturized electronics developed for SSAR have since be used on the REMUS Autonomous Underwater Vehicles (AUV's) as the primary navigation sensor for mission tracking and for autonomous docking. The tracking system developed for FOSS is based on these previous developments, in that the actual printed circuit cards and signal processing software are the same, however the frequency band utilized is lower due to the longer ranges.

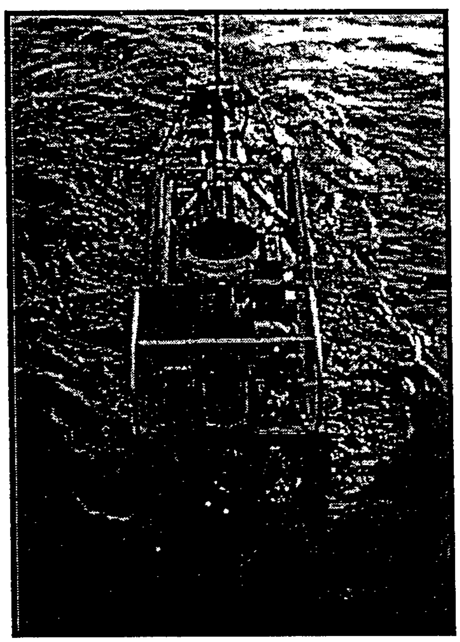

Figure 1: Photograph of TOSS vehicle showing RATS

2.0 Description

The RATS system consists of the following subassemblies:

a) Subsea Electronics bottle, This is the heart of RATS. It consists of the PC-104 computer, DSP board, Acoustics data acquisition system, Systron Donner 'Motion-Pak', and an internal three axis magnetometer heading sensor. All of the data acquisition and signal processing is done subsea, with control and results passed to a PC at the surface via a RS-232 port in the fiber-optic telemetry system. The Subsea electronics bottle has one end cap welded on, with the chassis mounted to the removable end cap. The heading sensor, motion sensor, and hydrophone array are precisely referenced mechanically, with respect to each